This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

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PERFORMANCE ASSESSMENT/COMPOSITE ANALYSIS MODELING TO SUPPORT A HOLISTIC STRATEGY FOR THE CLOSURE OF F AREA, A LARGE NUCLEAR COMPLEX AT THE SAVANNAH RIVER SITE

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ABSTRACT

A performance-based approach is being used at the Savannah Rive Site to close the F Area Complex. F Area consists of a number of large industrial facilities including plutonium separations, uranium fuel fabrication, tanks for storing high level waste and a number of smaller operations. A major part of the overall closure strategy is the use of techniques derived from the Performance Assessment and Composite Analysis requirements for low level waste disposal at DOE sites. This process will support deactivation, decommissioning and closure decisions to management, stakeholders and regulators.

INTRODUCTION

In order to support deactivation, decommissioning and closure decisions, a process has been developed that is analogous to the Performance Assessment/Composite Analysis system used to manage low level radioactive waste disposal in the DOE complex. This paper describes the Deactivation Analysis for the F Area Canyon and associated support facilities. The Deactivation Analysis is the analog of a Performance Assessment. Future work can integrate a number of Deactivation Analyses for F Area facilities into a holistic evaluation analysis similar to a Composite Analysis.

Final closure of F Area will be conducted in accordance with the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and under the SRS Federal Facility agreement (FFA), a tri-party regulatory agreement between DOE, the U.S. Environmental Protection Agency and the State of South Carolina.

PERFORMANCE CRITERIA

The specific performance criteria for the F Area Deactivation Analysis are adapted from USDOE Order 435.1 [1].

Performance Objectives

Production and support facilities shall be deactivated and decommissioned so that a reasonable expectation exists that the following performance objectives will be met:

- Dose to representative members of the public shall not exceed 25 mrem per year total effective dose equivalent (EDE) from all exposure pathways, excluding the dose from radon and its progeny in air.

- Dose to representative members of the public via the air pathway shall not exceed 10 mrem per year total EDE, excluding the dose from radon and its progeny.

- Release of radon shall be less than an average flux of 20 pCi/m^2/s at the surface of the facility. Alternatively, a limit of 0.5 pCi/L of air may be applied at the boundary of the facility.

In addition to the performance objectives, the Order requires, for purposes of establishing limits on the concentrations of radionuclides that may be disposed of near-surface, an assessment of impacts to water resources and to hypothetical persons assumed to inadvertently intrude into the low-level waste disposal facility. Table I lays out the performance measures and the associated points of compliance.

USDOE Order 435.1 states that "The performance assessment shall include calculations for a 1,000-y period after closure of potential doses to representative future members of the public and potential releases from the facility to provide a reasonable expectation that the performance objectives identified in this Chapter are not exceeded as a result of operation and closure of the facility."

Intruder Analysis

USDOE Order 435.1 provides a performance measure pertinent to impacts to hypothetical persons who are assumed to inadvertently intrude into a closed facility which specifies that calculated annual total EDE to such individuals not exceed 100 mrem for chronic exposure scenarios. For acute exposure scenarios, calculated doses are not to exceed 500 mrem total EDE. Institutional controls are assumed to be effective in deterring intrusion for at least 100 y following closure of the facility. Passive controls, in the form of engineered barriers or features of the site, can be claimed as further deterrents to intrusion.

In general, the chronic exposure scenarios address reasonable and credible pathways. However, consumption of groundwater and crop irrigation are exposure pathways that are excluded from the intruder analysis [2]; impacts of groundwater contamination are evaluated separately in this study.

Groundwater Analysis

USDOE Order 435.1 requires an analysis of groundwater concentrations of radionuclides leached from the facility in order to address both the all-pathways performance objective and the water resources impact assessment requirement (Table I). Protection of the public according to the stated performance objectives requires that calculated annual dose to a hypothetical future member of the public shall not exceed 25 mrem total EDE from all exposure pathways, including potential ingestion of groundwater. The point of compliance is the point of highest calculated dose beyond a 100-meter buffer zone surrounding the facility.

Table I. DOE Order 435.1 Performance Objectives, Assessment Requirements, and Points of Compliance

Component	Performance Objective	Point of Compliance
All pathways	≤ 25 mrem in a year, not including doses from radon and progeny	Point of highest projected dose or concentration beyond a 100-m buffer zone surrounding the closed facility
Air pathway	≤ 10 mrem in a year, not including doses from radon and progeny	Point of highest projected dose or concentration beyond a 100-m buffer zone surrounding the closed facility
Radon	either (1) an average flux of ≤ 20 pCi/m^2/s, or	Closed facility surface
	(2) an air concentration of ≤ 0.5 pCi/L	Point of highest projected dose or concentration beyond a 100-m buffer zone surrounding the closed facility
Assessment Requirement	Measure	Point of Compliance
Hypothetical inadvertent intruder	100 mrem in a year from chronic exposure	Closed facility
	500 mrem from a single event	Closed facility
Impact on water resources	The SRS interpretation is that concentrations of radioactive contaminants should not exceed standards for public drinking water supplies established by the USEPA (40 CFR Part 141).	Point of highest projected dose or concentration beyond a 100-m buffer zone surrounding the closed facility

For the water resources impact assessment requirement, USDOE Order 435.1 does not specify either dose or concentration limits for radionuclides in water. Therefore, there is some ambiguity in applying the requirement even though, as described previously, at SRS the performance measure is interpreted as requiring that concentrations of contaminants in groundwater should not exceed values specified in USEPA standards for public drinking water supplies (40 CFR Part 141).

The SRS is one of the USDOE sites designated as being on the National Priorities List (NPL) by CERCLA. In addition, SRS is responsible for managing hazardous waste and the associated facilities in accordance with the Resource Conservation and Recovery Act (RCRA). Groundwater that is contaminated by hazardous waste or from hazardous waste management processes or facilities is treated and managed under RCRA. As a result, all contamination of groundwater at SRS is regulated under CERCLA or RCRA. The maximum contaminant levels (MCLs) promulgated under the Safe Drinking Water Act (40 CFR 141) are used as the basis for determining groundwater cleanup requirements.

The Primary Drinking Water Standards for radionuclides, promulgated on December 7, 2000, are used in this Deactivation Analysis [3]. The current 4 mrem/year standard for beta and/or photon emitters in drinking water requires that MCLs be developed based on internal dosimetry data from National Bureau of Standards (NBS) Handbook 69 [4] and specified MCLs for ^{3}H and ^{90}Sr. A listing of the resulting MCLs is available in the Implementation Guidance for Radionuclides [5]. There are several radionuclides for which MCLs are not available in this listing. For these an MCL can be derived assuming a limit of 4 mrem/year EDE and internal dosimetry based on ICRP Publication 30 [6]. Table II compares the MCL and the concentration equivalent to the 25 mrem/year all pathway dose.

Air Analysis

The all-pathways performance objective of USDOE Order 435.1 includes all modes of exposure, including the air pathway, but excluding exposures to radon and short-lived progeny. In addition to this objective, calculated dose via the air pathway is not to exceed 10 mrem/year total EDE, again excluding dose from radon and short-lived progeny (Table I). Again, the point of compliance is the point of highest calculated dose beyond a 100-meter buffer zone surrounding the closed facility.

Radon Emanation Analysis

Radon is addressed separately in a performance objective under USDOE Order 435.1, with separate applicable limits. In most cases, the limit for radon should be an average ground surface emanation rate of 20 $pCi/m^2/s$, which applies in this Deactivation Analysis.

TIME OF ASSESSMENT, POINT OF ASSESSMENT AND INSTITUTIONAL CONTROL PERIOD

The Deactivation Analysis will use a time of assessment of 1000 years and a point of assessment for the groundwater pathway of 100 meters from the facility. These values have been agreed to by WSRC and DOE-SR for use in low-level radioactive waste disposal facility performance assessments. For this study, an institutional control period of 300 years was used. This time period is currently under consideration as a site-wide policy, but at the time of this writing has not been approved.

Table II. Comparison of MCLs and Allowable Groundwater Concentrations Based on the 25 mrem per Year Performance Objective for Off-Site Individuals

Radionuclide	MCL, pCi/L	Allowable Concentration Based on 25 mrem per year, pCi/L
H-3	20,000	540,000
C-14	2,000	17,000
Ni-59	300	170,000
Se-79	700	4,100
Sr-90	8	250
Tc-99	900	26,000
Sn-126	300	1,900
I-129	1	130
Ra-226	5	31
Th-229	15	9.6
Th-230	15	64
Th-232	15	13
U-233	280,000 (30 μg/L)	130
U-234	190,000 (30 μg/L)	130
U-235	65 (30 μg/L)	140
U-236	1,900 (30 μg/L)	140
U-238	10 (30 μg/L)	150
Np-237	15	8.9
Pu-238	15	8.9
Pu-239	15	8.1
Pu-240	15	8.1
Pu-241	300	400
Pu-242	15	8.3
Am-241	15	7.6
Am-243	15	7.6
Cm-244	15	17
Cm-246	15	7.6

KEY MODELING ASSUMPTIONS AND PARAMETERS TO SATISFY DOE ORDER 435.1

For protection of the public and the assessment of impacts to water resources under DOE Order 435.1, exposure pathways involving direct ingestion of groundwater and release of volatile radionuclides to the atmosphere are the pathways of dominant concern for this Deactivation Analysis. For the intruder analysis, there is no clear dominance of exposure pathways or scenarios, and doses vary greatly by radionuclide.

Assumptions of greatest importance to the projection of groundwater concentrations are those that affect the projection of release from the closed facility and subsequent transport. Release from the waste forms is a strong function of the amount of water infiltrating the closed facility, the manner in which radionuclides are bound to the facility, physical/chemical sorption properties of individual radionuclides, solubility of the radionuclides, and the presence of engineered barriers to water flow. The amount of infiltrating water and hydraulic properties of the soil matrix are important to the estimation of the transport to the water table; however, over long periods of time, when steady-state conditions are approached, hydraulic properties become less important because the flow rate becomes controlled by the rate water infiltrates to the source zone. Ultimately, groundwater concentrations are a function of the rate radionuclides reach the water table, which are affected by the parameters listed above, and of the hydraulic properties of the aquifer matrix. Simulation of these important processes requires a number of generally simplifying assumptions. Those that most affect the projected groundwater concentrations are: 1) representation of the end state of the facility as concrete rubble; 2) no engineered cover system is assumed to be in place; 3) sorption is assumed to be adequately represented by non-site-specific sorption coefficients (K_ds) for many radionuclides and materials; and 4) all radionuclides are assumed to exist as surface contamination, and are available for transport. These assumptions and their results will have to be considered in the final closure of F Area, under CERCLA.

Assumptions of greatest importance to the estimation of dose resulting from release of volatile radionuclides to air have to do with the rate at which volatile radionuclides are released to the atmosphere and the time at which the releases occur.

For estimation of dose to inadvertent intruders, exposure scenario definitions (assumptions) are perhaps most critical to the DOE Order 435.1 performance analysis. Probably the most important assumptions are: 1) the inadvertent intruder has no knowledge of prior activities at the site: 2) the intruder will build a home or drill a well at the location of the closed facility, rather than in uncontaminated areas; 3) the intruder excavates or drills at the earliest time possible relative to degradation estimates for the various materials; and 4) exhumed contaminated material is mixed with uncontaminated soil, and a garden is planted in the resulting mix. These important assumptions tend to maximize the calculated dose to the intruder, and thus provide a pessimistic evaluation of performance of the closed facility with respect to impacts on intruders.

The sorption coefficients (K_ds) assumed in the analyses of release from waste forms are listed in Table III. Selection of K_ds was made according to the following rationale. Site-specific values of soil K_ds are considered most appropriate; when available, they were used. Next, the comprehensive listing of default values by Sheppard and Thibault [7] was consulted for K_ds in soil. The sandy soil K_d was selected for "soil" because this value tends to be lower than for other soil types, and thus is conservative (i.e., may overestimate radionuclide mobility) with respect to water resource impacts. For concrete, a listing of K_ds by Bradbury and Sarott [8] was consulted. For isotopes of Pu, a limit on solubility of these elements in a cementitious environment of concrete rubble, where the pH is expected to be in excess of 7, is assumed to affect availability for transport. The solubility limit used was developed in (McDowell-Boyer et al., [9] and listed in Table IV.

MODELING WORK

The facilities included in the initial modeling exercise were the F-Area Canyon, the F-Area Canyon Outside Facilities and the F-Area Sand Filters. These facilities are shown in Figure 1. A map of the water table elevation contours is shown in Figure 2.

The PATHRAE performance assessment computer program [15] was used for this work. In order to calculate allowable residual inventories, one curie of each radionuclide of interest was used for each facility. The peak groundwater concentration before 1000 years, or the concentration at 1000 if the peak concentration occurs after 1000 years, was compared to the maximum allowed concentration for each radionuclide, and the inventory that would have resulted in the maximum allowed concentration was calculated:

Allowable Inventory = 1 Ci (Input Inventory)* MCL (pCi/L)/ Peak Concentration (pCi/L).

Three intruder exposure pathways were analyzed, Food Grown on Site, Direct Gamma Exposure and Dust Inhalation. These are the components of the standard intruder scenarios (agricultureal, resident and post-drilling) used in the SRS Performance Assessments (McDowell-Boyer et al., 2000). The doses from each pathway were summed to give the total intruder dose per curie of residual inventory. The allowable residual inventory for each radionuclide based on the intruder analysis was calculated using:

Allowable Inventory = 1 Ci (Input Inventory)*100 mrem/yr/ Total Dose (mrem/yr).

The key model inputs for the three facilities are given in Table V, VI and VII.

The overall allowable inventory is the lower of the ones calculated from the groundwater and intruder results. Tables VIII, IX and X summarize the results for the Canyon, Outside Facilities and Sand Filters, respectively.

Table III. Elemental Sorption Coefficients (K_ds) for Radionuclides of Interest

	K_d (ml/g)	
Nuclide	Soil[a]	Concrete[b]
Am	1900	5000
C	2[c]	7000
Cm	4000	5000
Cs	330[d]	2
H	0.001	0.001
I	0.6[e]	2
Ni	400	100
Np	5	5000
Pu	300[f]	5000
Ra	500	50
Se	55	0.1
Sn	130	1000
Sr	10[d]	1
Tc	0.36[e]	1
Th	3200	5000
U	800[g]	2000

[a] Values are for sand from Sheppard and Thibault [7], unless otherwise noted.
[b] Values from Bradbury and Sarott [8].
[c] Site-specific value from McIntyre [10].
[d] Site-specific value from Hoeffner [11].
[e] Site-specific value from Hoeffner [12].
[f] Site specific value from Cook [13].
[g] Site specific value from Serkiz[14].

Table IV. Solubility Limit for Plutonium

	Solubility Limit	
Element	M	g/cc
Pu	4.4×10^{-13}	1.1×10^{-13}

Figure 1. F-Area Canyon (211-F and Sand Filters (291-f and 291-1F).

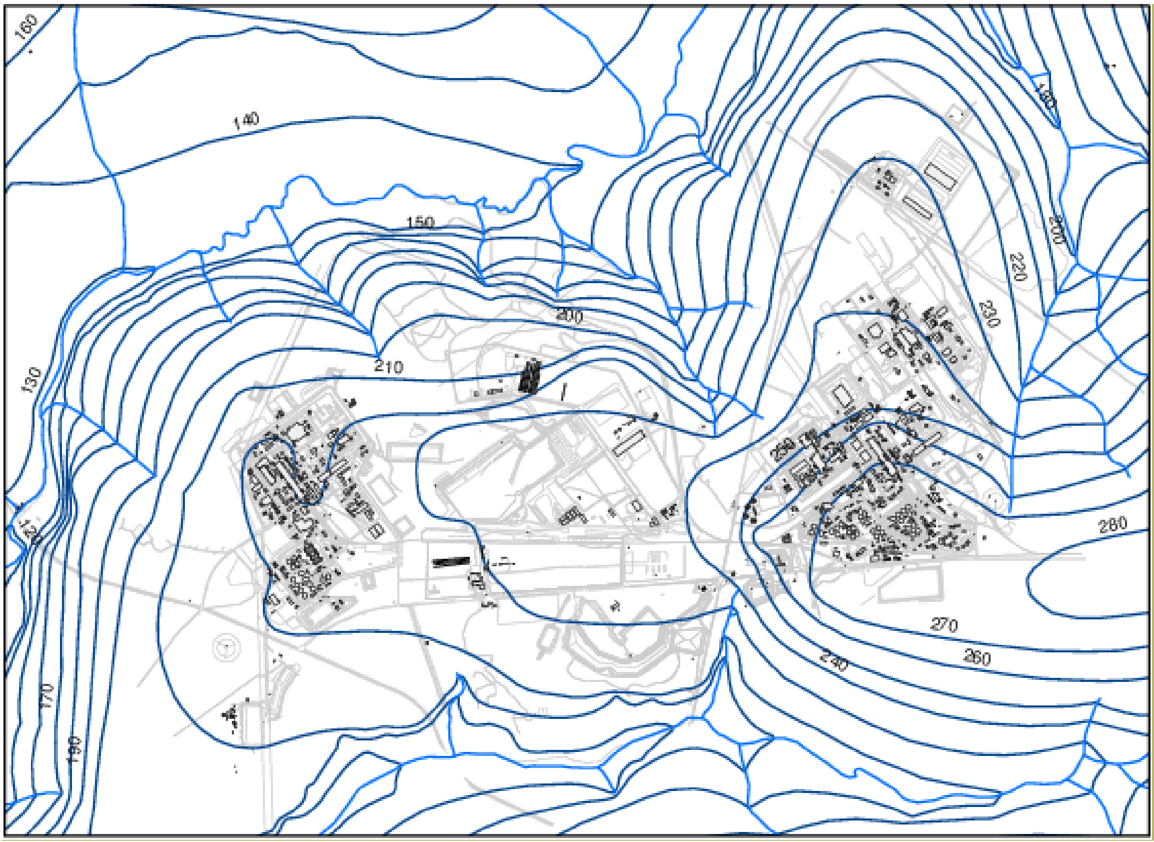

Figure 2. Water table elevations in the General Separations Area

Table V. Key Parameters for the F Area Canyon Model			
Variable	Property	Value	Source
NISO	Number of Isotopes	27	CA Inventory Report
XLP	Length of Facility	35 m	Map Measurement
WIDTH	Width of Facility	250 m	Map Measurement
ARHO	Density of Aquifer	1600 kg/m^3	EAV PA
ALDIS	Longitudinal Dispersivity	1.0 m	Assumption
DY	Transverse Dispersion	0	Assumption
DZ	Vertical Dispersion	0	Assumption
SS	Fraction of Saturation	0, Flag to calculate internally	PATHRAE Suggestion
SR	Residual Saturation	0.7	EAV PA
PV	Sat. Conductivity of Vertical Zone	100 m/y	EAV PA
NM	No. of Mesh Points	20	PATHRAE Suggestion
NMY	No. Mesh Points Y	5	PATHRAE Suggestion
NMZ	No. Mesh Points Z	5	PATHRAE Suggestion
XCT	Cover Thickness	2.0 m	Assumption
XWT	Waste Thickness	13.0 m	Assumption
TWV	Waste Volume	7560 m^3	LxWxT
XW	Distance to Well	-1, Flag to use 1 m and 100 m	Assumption
YW	Well Distance Off Centerline	0 m	Assumption
RHO	Density of Waste	1600 kg/m^3	EAV PA
CANLIFE	Waste Container Lifetime	0 yr	Assumption
IFL	Decay Chain Flags	1,1,1,1,1,1,1	Inventory Report
XPERC	Water Infiltration to Waste	0.4 m/yr	Site Average
VA	Horizontal Velocity of Aquifer	2.1 m/yr	Tank 20 Closure Plan
PORA	Porosity of Aquifer	0.44	EAV PA
XAQD	Distance from waste to Aquifer	28 – 2- 13 = 13 m	EGG DATA
XVV	Vertical velocity in Unsaturated Zone	Calculated in Code	
XLC	Well Screen Length	1.5 m	Thickness of top node
XALE	Surface Erosion Rate	3.0 x 10^{-6} m/yr	EAV PA
RUNF	Precipitation Runoff Rate	0.4 m/yr	EAV PA
PORU	Porosity of Unsaturated Zone	0.44	EAV PA
BDENS	Bulk Density of Soil	1600 kg/m^3	EAV PA
XLLI	Leach Constant	Based on Concrete	Bradbury & Sarott

Table VI. Key Parameters for the Outside Facility Model			
Variable	Property	Value	Source
NISO	Number of Isotopes	27	Inventory Report
XLP	Length of Facility	14 m	Map Measurement
WIDTH	Width of Facility	300 m	Map Measurement
ARHO	Density of Aquifer	1600 kg/m^3	EAV PA
ALDIS	Longitudinal Dispersivity	1.0 m	Assumption
DY	Transverse Dispersion	0	Assumption
DZ	Vertical Dispersion	0	Assumption
SS	Fraction of Saturation	0, Flag to calculate internally	PATHRAE Suggestion
SR	Residual Saturation	0.7	EAV PA
PV	Sat. Conductivity of Vertical Zone	100 m/y	EAV PA
NM	No. of Mesh Points	20	PATHRAE Suggestion
NMY	No. Mesh Points Y	5	PATHRAE Suggestion
NMZ	No. Mesh Points Z	5	PATHRAE Suggestion
XCT	Cover Thickness	2.0 m	Assumption
XWT	Waste Thickness	3.0 m	Assumption
TWV	Waste Volume	12,600 m^3	LxWxT
XW	Distance to Well	-1, Flag to use 1 m and 100 m	Assumption
YW	Well Distance Off Centerline	0 m	Assumption
RHO	Density of Waste	1600 kg/m^3	EAV PA
CANLIFE	Waste Container Lifetime	0 yr	Assumption
IFL	Decay Chain Flags	1,1,1,1,1,1,1	Inventory Report
XPERC	Water Infiltration to Waste	0.4 m/yr	Site Average
VA	Horizontal Velocity of Aquifer	2.1 m/yr	Tank 20 Closure Plan
PORA	Porosity of Aquifer	0.44	EAV PA
XAQD	Distance from waste to Aquifer	28 - 2 - 3 = 23 m	EGG DATA
XVV	Vertical velocity in Unsaturated Zone	Calculated in Code	
XLC	Well Screen Length	1.5 m	Thickness of top node
XALE	Surface Erosion Rate	3.0 x 10^{-6} m/yr	EAV PA
RUNF	Precipitation Runoff Rate	0.4 m/yr	EAV PA
PORU	Porosity of Unsaturated Zone	0.44	EAV PA
BDENS	Bulk Density of Soil	1600 kg/m^3	EAV PA
XLLI	Leach Constant	Based on Concrete	Bradbury & Sarott

Table VII. Key Parameters in Sand Filter Model

Variable	Property	Value	Source
NISO	Number of Isotopes	27	CA Inventory Report
TIMOP	Time of Operations	0	
XLP	Length of Facility	31 m	Map Measurement
WIDTH	Width of Facility	183 m	Map Measurement
ARHO	Density of Aquifer	1600 kg/m^3	EAV PA
ALDIS	Longitudinal Dispersivity	1.0 m	Assumption
DY	Transverse Dispersion	0	Assumption
DZ	Vertical Dispersion	0	Assumption
SS	Fraction of Saturation	0, Flag to calculate internally	PATHRAE Suggestion
SR	Residual Saturation	0.7	EAV PA
PV	Sat. Conductivity of Vertical Zone	100 m/y	EAV PA
NM	No. of Mesh Points	20	PATHRAE Suggestion
NMY	No. Mesh Points Y	5	PATHRAE Suggestion
NMZ	No. Mesh Points Z	5	PATHRAE Suggestion
XCT	Cover Thickness	1.0 m	Assumption
XWT	Waste Thickness	7.1 m	Sykes and Harper
TWV	Waste Volume	39,600 m^3	LxWxT
XW	Distance to Well	-1, Flag to use 1m and 100 m	Assumption
YW	Well Distance Off Centerline	0 m	Assumption
RHO	Density of Waste	1600 kg/m^3	Same as soil
CANLIFE	Waste Container Lifetime	0 yr	Assumption
IFL	Decay Chain Flags	1,1,1,1,1,1,1	
XPERC	Water Infiltration to Waste	0.4 m/yr	Site Average
VA	Horizontal Velocity of Aquifer	2.1 m/yr	Tank 20 Closure Plan
PORA	Porosity of Aquifer	0.44	EAV PA
XAQD	Distance from waste to Aquifer	28 - 1 – 7.1 m - m = 20 m	EGG DATA
XVV	Vertical velocity in Unsaturated Zone	Calculated in Code	
XLC	Well Screen Length	1.5 m	Thickness of top node
XALE	Surface Erosion Rate	3.0 x 10^{-6} m/yr	EAV PA
RUNF	Precipitation Runoff Rate	0.4 m/yr	EAV PA
PORU	Porosity of Unsaturated Zone	0.3	EAV PA
BDENS	Bulk Density of Soil	1600 kg/m^3	
XLLI	Leach Constant	Based on Concrete	Bradbury & Sarott

Table VIII. Results for the F-Area Canyon

Radionuclide	Concentration Limit pCi/L	GW Peak Conc. pCi/L-Ci	GW Limit Ci	Intruder Dose mrem/Ci	Intruder Limit Ci	Overall Limit Ci	Overall Limit GBq
H-3	2.0E+04	3.8E+02	5.2E+01	8.0E-25	1.3E+26	5.2E+01	1.9E+03
C-14	2.0E+03	7.2E-01	2.8E+03	6.8E-07	1.5E+08	2.8E+03	1.0E+05
Ni-59	3.0E+02		1.0E+20	6.7E-05	1.5E+06	1.5E+06	5.5E+07
Se-79	7.0E+02		1.0E+20	3.1E-01	3.2E+02	3.2E+02	1.2E+04
Sr-90	8.0E+00		1.0E+20	4.9E-06	2.1E+07	2.1E+07	7.6E+08
Tc-99	9.0E+02	4.2E+03	2.2E-01	1.5E-03	6.7E+04	2.2E-01	8.0E+00
Sn-126	3.0E+02		1.0E+20	1.0E-03	9.8E+04	9.8E+04	3.6E+06
I-129	1.0E+00	2.4E+03	4.2E-04	8.2E-03	1.2E+04	4.2E-04	1.5E-02
Cs-137	2.0E+02		1.0E+20	5.5E-03	1.8E+04	1.8E+04	6.7E+05
Ra-226	5.0E+00		1.0E+20	1.1E-05	9.3E+06	9.3E+06	1.7E+04
Th-230	1.5E+01		1.0E+20	3.3E-04	3.1E+05	3.1E+05	1.1E+07
Th-232	1.3E+01		1.0E+20	8.7E-09	1.1E+10	1.1E+10	4.2E+11
U-233	1.3E+02		1.0E+20	5.0E-02	2.0E+03	2.0E+03	7.4E+04
U-234	1.3E+02		1.0E+20	5.0E-02	2.0E+03	2.0E+03	3.5E+03
U-235	6.5E+01		1.0E+20	1.0E+00	9.6E+01	9.6E+01	8.1E+04
U-236	1.4E+02		1.0E+20	4.6E-02	2.2E+03	2.2E+03	8.2E+04
U-238	1.0E+01		1.0E+20	4.5E-02	2.2E+03	2.2E+03	6.2E+03
Np-237	8.9E+00	5.3E-02	1.7E+02	3.2E-01	3.1E+02	1.7E+02	2.5E+05
Pu-238	8.9E+00		1.0E+20	1.5E-02	6.9E+03	6.9E+03	2.1E+04
Pu-239	8.1E+00		1.0E+20	1.8E-01	5.7E+02	5.7E+02	2.1E+04
Pu-240	8.1E+00		1.0E+20	1.8E-01	5.7E+02	5.7E+02	2.0E+12
Pu-241	3.0E+02		1.0E+20	1.8E-09	5.4E+10	5.4E+10	2.2E+04
Pu-242	8.3E+00		1.0E+20	1.7E-01	6.0E+02	6.0E+02	2.2E+04
Am-241	7.6E+00		1.0E+20	1.7E-01	5.8E+02	5.8E+02	8.5E+03
Am-243	7.6E+00		1.0E+20	4.3E-01	2.3E+02	2.3E+02	3.1E+09
Cm-244	1.5E+01		1.0E+20	1.2E-06	8.4E+07	8.4E+07	7.4E+04
Cm-246	7.6E+00		1.0E+20	2.1E-01	4.7E+02	4.7E+02	3.4E+08

Table IX. Results for the F Canyon Outside Facilities

Radionuclide	Concentration Limit	GW Peak Conc.	GW Limit	Intruder Dose	Intruder Limit	Overall Limit	Overall Limit
	pCi/L	pCi/L-Ci	Ci	mrem/Ci	Ci	Ci	GBq
H-3	2.0E+04	7.9E+02	2.5E+01	4.0E-54	2.5E+55	2.5E+01	9.4E+02
C-14	2.0E+03	6.4E+00	3.1E+02	6.1E-06	1.6E+07	3.1E+02	1.2E+04
Ni-59	3.0E+02		1.0E+20	5.8E-04	1.7E+05	1.7E+05	1.0E+07
Se-79	7.0E+02		1.0E+20	9.8E-02	1.0E+03	1.0E+03	6.1E+04
Sr-90	8.0E+00		1.0E+20	6.7E-06	1.5E+07	1.5E+07	8.9E+08
Tc-99	9.0E+02	1.5E+04	6.1E-02	3.8E-09	2.6E+10	6.1E-02	2.3E+00
Sn-126	3.0E+02		1.0E+20	9.0E-03	1.1E+04	1.1E+04	6.7E+05
I-129	1.0E+00	1.1E+04	9.5E-05	1.5E-05	6.5E+06	9.5E-05	3.5E-03
Cs-137	2.0E+02		1.0E+20	4.6E-02	2.2E+03	2.2E+03	8.0E+04
Ra-226	5.0E+00		1.0E+20	9.2E-05	1.1E+06	1.1E+06	3.1E+03
Th-230	1.5E+01		1.0E+20	2.9E-03	3.4E+04	3.4E+04	2.0E+06
Th-232	1.3E+01		1.0E+20	7.8E-08	1.3E+09	1.3E+09	7.7E+10
U-233	1.3E+02		1.0E+20	4.4E-01	2.3E+02	2.3E+02	1.3E+04
U-234	1.3E+02		1.0E+20	4.4E-01	2.3E+02	2.3E+02	4.0E+02
U-235	6.5E+01		1.0E+20	9.4E+00	1.1E+01	1.1E+01	1.4E+04
U-236	1.4E+02		1.0E+20	4.1E-01	2.4E+02	2.4E+02	1.4E+04
U-238	1.0E+01		1.0E+20	4.1E-01	2.5E+02	2.5E+02	1.7E+03
Np-237	8.9E+00	1.9E-04	4.7E+04	3.0E+00	3.4E+01	3.4E+01	4.4E+04
Pu-238	8.9E+00		1.0E+20	1.4E-01	7.4E+02	7.4E+02	3.8E+03
Pu-239	8.1E+00		1.0E+20	1.6E+00	6.4E+01	6.4E+01	3.8E+03
Pu-240	8.1E+00		1.0E+20	1.6E+00	6.4E+01	6.4E+01	3.6E+11
Pu-241	3.0E+02		1.0E+20	1.6E-08	6.1E+09	6.1E+09	4.0E+03
Pu-242	8.3E+00		1.0E+20	1.5E+00	6.9E+01	6.9E+01	3.2E+03
Am-241	7.6E+00		1.0E+20	1.6E+00	6.4E+01	6.4E+01	1.1E+03
Am-243	7.6E+00		1.0E+20	3.8E+00	2.6E+01	2.6E+01	5.6E+08
Cm-244	1.5E+01		1.0E+20	1.1E-05	9.4E+06	9.4E+06	1.3E+04
Cm-246	7.6E+00		1.0E+20	1.9E+00	5.3E+01	5.3E+01	4.6E+07

Table X. Results for the F Area Sand Filters

Radionuclide	Concentration Limit pCi/L	GW Peak Conc. pCi/L-Ci	GW Limit Ci	Intruder Dose mrem/Ci	Intruder Limit Ci	Overall Limit Ci	Overall Limit GBq
H-3	2.0E+04	5.8E+02	3.5E+01	1.3E-31	7.7E+32	3.5E+01	1.3E+03
C-14	2.0E+03	2.1E+00	9.8E+02	3.9E-06	2.6E+07	9.8E+02	3.6E+04
Ni-59	3.0E+02		1.0E+20	3.8E-04	2.7E+05	2.7E+05	9.9E+06
Se-79	7.0E+02		1.0E+20	7.6E-01	1.3E+02	1.3E+02	4.9E+03
Sr-90	8.0E+00		1.0E+20	1.8E-05	5.7E+06	5.7E+06	2.1E+08
Tc-99	9.0E+02	9.4E+02	9.6E-01	2.0E-04	5.0E+05	9.6E-01	3.5E+01
Sn-126	3.0E+02		1.0E+20	5.8E-03	1.7E+04	1.7E+04	6.4E+05
I-129	1.0E+00	6.0E+03	1.7E-04	4.5E-03	2.2E+04	1.7E-04	6.1E-03
Cs-137	2.0E+02		1.0E+20	6.6E-05	1.5E+06	1.5E+06	5.6E+07
Ra-226	5.0E+00		1.0E+20	1.8E-05	5.7E+06	5.7E+06	3.0E+03
Th-230	1.5E+01		1.0E+20	1.8E-03	5.4E+04	5.4E+04	2.0E+06
Th-232	1.3E+01		1.0E+20	4.9E-08	2.0E+09	2.0E+09	7.6E+10
U-233	1.3E+02		1.0E+20	2.7E-01	3.7E+02	3.7E+02	1.4E+04
U-234	1.3E+02		1.0E+20	2.7E-01	3.7E+02	3.7E+02	1.5E+04
U-235	6.5E+01		1.0E+20	2.5E-01	4.0E+02	4.0E+02	1.5E+04
U-236	1.4E+02		1.0E+20	2.5E-01	4.0E+02	4.0E+02	1.5E+04
U-238	1.0E+01		1.0E+20	2.5E-01	4.1E+02	4.1E+02	3.2E+03
Np-237	8.9E+00	1.6E-03	5.6E+03	1.2E+00	8.6E+01	8.6E+01	4.4E+04
Pu-238	8.9E+00		1.0E+20	8.4E-02	1.2E+03	1.2E+03	3.7E+03
Pu-239	8.1E+00		1.0E+20	1.0E+00	1.0E+02	1.0E+02	3.8E+03
Pu-240	8.1E+00		1.0E+20	9.7E-01	1.0E+02	1.0E+02	3.6E+11
Pu-241	3.0E+02		1.0E+20	1.0E-08	9.8E+09	9.8E+09	3.9E+03
Pu-242	8.3E+00		1.0E+20	9.4E-01	1.1E+02	1.1E+02	5.6E+03
Am-241	7.6E+00		1.0E+20	6.6E-01	1.5E+02	1.5E+02	3.7E+03
Am-243	7.6E+00		1.0E+20	1.0E+00	1.0E+02	1.0E+02	5.6E+08
Cm-244	1.5E+01		1.0E+20	6.6E-06	1.5E+07	1.5E+07	1.4E+04
Cm-246	7.6E+00		1.0E+20	1.2E+00	8.1E+01	8.1E+01	2.1E+08

USE OF THE RESIDUAL INVENTORY LIMITS

The residual inventory limits calculated here must be administered using the sum of fractions technique. The fraction of the limit of each radionuclide in the residual inventory must be found, and these fractions summed. The sum must be less than one for the total inventory to be compliant with the results of this analysis.

For example, if there are two radionuclides in the residual inventory, A and B, with limits of 1 Ci and 10 Ci, respectively, and there are 0.5 Ci of A and 7.5 Ci of B, then the sum of fractions is:

$$(0.5/1.0) + (7.5/10) = 1.25$$

and the residual inventory is not acceptable, even though the individual inventories are below the limit.

Other considerations may play a role in determining whether a given residual inventory is acceptable. Examples are criticality concerns and the NRC Class C concentrations.

The limits given in this report were calculated using a number of conservative assumptions and parameter estimates. As the knowledge of these facilities increases as deactivation work progresses, this report will be revised using assumptions and parameters derived from actual measurements.

CONCLUSIONS

A performance-based methodology for determining allowable residual inventories for the F-Area Canyon and associated support facilities has been developed and implemented. This provides a quantitative basis that will support planning the deactivation, decommissioning and closure of a major nuclear production facility.

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